1

Applications of Advanced Composites in Aircraft Structures

Some of the milestones in the implementation of advanced composites on aircraft and rotorcraft are discussed in this chapter. Specific applications have been selected that highlight various phases that the composites industry went through while trying to extend the application of composites.

The application of composites in civilian or military aircraft followed the typical stages that every new technology goes through during its implementation. At the beginning, limited application on secondary structure minimized risk and improved understanding by collecting data from tests and fleet experience. This limited usage was followed by wider applications, first in smaller aircraft, capitalizing on the experience gained earlier. More recently, with the increased demand on efficiency and low operation costs, composites are being applied widely on larger aircraft.

Perhaps the first significant application of advanced composites was on the Akaflieg Phönix FS-24 (Figure 1.1) in the late 1950s. What started as a balsa wood and paper sailplane designed by professors at the University of Stuttgart and built by the students was later transformed into a fibreglass/balsa wood sandwich design. Eight planes were eventually built.

The helicopter industry was among the first to recognize the potential of the composite materials and use them on primary structure. The main and tail rotor blades with their beam-like behaviour were one of the major structural parts designed and built with composites towards the end of the 1960s. One such example is the Aerospatiale Gazelle (Figure 1.2). Even though, to first order, helicopter blades can be modelled as beams, the loading complexity and the multiple static and dynamic performance requirements (strength, buckling, stiffness distribution, frequency placement, etc.) make for a very challenging design and manufacturing problem.

In the 1970s, with the composites usage on sailplanes and helicopters increasing, the first all-composite planes appeared. These were small recreational or aerobatic planes. Most notable among them were the Burt Rutan designs such as the Long EZ and Vari-Eze (Figure 1.3). These were largely co-cured and bonded constructions with very limited numbers of fasteners. Efficient aerodynamic designs with mostly laminar flow and light weight led to a combination of speed and agility.

Design and Analysis of Composite Structures: With Applications to Aerospace Structures, Second Edition. Christos Kassapoglou.

Figure 1.1 Akaflieg Phönix FS-24 (Courtesy of Deutsches Segelflugzeugmuseum; see Plate 1 for the colour figure)

Figure 1.2 Aerospatiale SA 341G Gazelle (Copyright Jenny Coffey, printed with permission; see Plate 2 for the colour figure)

Figure 1.3 Long EZ and Vari-Eze. (Vari-Eze photo: courtesy of Stephen Kearney; Long EZ photo: courtesy of Ray McCrea; see Plate 3 for the colour figure)

Up to that point, usage of composites was limited and/or was applied to small aircraft with relatively easy structural requirements. In addition, the performance of composites was not completely understood. For example, their sensitivity to impact damage and its implications for design only came to the forefront in the late 1970s and early 1980s. At that time, efforts to build the first all-composite airplane of larger size began with the LearFan 2100

Figure 1.4 LearAvia LearFan 2100 (Copyright Thierry Deutsch; see Plate 4 for the colour figure)

(Figure 1.4). This was the first civil aviation all-composite airplane to seek FAA certification (see Section 2.2). It used a pusher propeller and combined high speed and low weight with excellent range and fuel consumption. Unfortunately, while it met all the structural certification requirements, delays in certifying the drive system and the death of Bill Lear the visionary designer and inventor behind the project, kept the LearFan from making it into production and the company, LearAvia, went bankrupt.

The Beech Starship I (Figure 1.5) which followed on the heels of the LearFan in the early 1980s was the first all-composite airplane to obtain FAA certification. It was designed to the new composite structure requirements specially created for it by the FAA. These requirements were the precursor of the structural requirements for composite aircraft as they are today. Unlike the LearFan which was a more conventional skin-stiffened structure with frames and stringers, the Starship fuselage was made of sandwich (graphite/epoxy facesheets with Nomex® core) and had a very limited number of frames, increasing cabin head room for a given cabin diameter and minimizing fabrication cost. It was co-cured in large pieces that were bonded together and, in critical connections such as the wing-box or the main fuselage joints, were also fastened. Designed also by Burt Rutan, the Starship was meant to have mostly laminar

Figure 1.5 Beech (Raytheon Aircraft) Starship I (Courtesy of Brian Bartlett; see Plate 5 for the colour figure)

Figure 1.6 Airbus A-320 (Courtesy of Brian Bartlett; see Plate 6 for the colour figure)

flow and increased range through the use of efficient canard design and blended main wing. Two engines with pusher propellers located at the aft fuselage were to provide enough power for high cruising speed. In the end, the aerodynamic performance was not met and the fuel consumption and cruising speeds missed their targets by a small amount. However, structurally the Starship I proved that the all-composite aircraft could be designed and fabricated to meet the stringent FAA requirements. In addition, invaluable experience was gained in analysis and testing of large composite structures and new low-cost structurally robust concepts were developed for joints and sandwich structure in general.

With fuel prices rising, composites with their reduced weight became a very attractive alternative to the metal structure. Applications in the large civilian transport category started in the early 1980s with the Boeing 737 horizontal stabilizer which was a sandwich construction and continued with larger-scale application on the Airbus A-320 (Figure 1.6). The horizontal and vertical stabilizers as well as the control surfaces of the A-320 are made of composite materials.

The next significant application of composites on primary aircraft structure came in the 1990s with the Boeing 777 (Figure 1.7) where, in addition to the empennage and control surfaces, the main floor beams are also made out of composites.

Figure 1.7 Boeing 777 (Courtesy of Brian Bartlett; see Plate 7 for the colour figure)

Figure 1.8 Airbus A-380 (Courtesy of Bjoern Schmitt, World of Aviation.de; see Plate 8 for the colour figure)

Despite the use of innovative manufacturing technologies which started with early robotics applications on the A320 and continued with significant automation (tape layup) on the 777, the cost of composite structures was not attractive enough to lead to an even larger-scale (e.g. entire fuselage and/or wing structure) application of composites at that time. The Airbus A-380 (Figure 1.8) in the new millennium, was the next major application with glass/aluminium (glare) composites on the upper portion of the fuselage and glass and graphite composites in the centre wing-box, floor beams and aft pressure bulkhead.

Already in the 1990s, the demand for more efficient aircraft with lower operation and maintenance costs made it clear that more usage of composites was necessary for significant reductions in weight in order to gain in fuel efficiency. In addition, improved fatigue lives and improved corrosion resistance compared with aluminium suggested that more composites on aircraft were necessary. This, despite the fact that the cost of composites was still not competitive with aluminium and the stringent certification requirements would lead to increased certification cost.

Boeing was the first to commit to a composite fuselage and wing with the 787 (Figure 1.9) launched in the first decade of the new millennium. Such extended use of composites, about 50% of the structure (combined with other advanced technologies) would give the efficiency improvement (increased range, reduced operation and maintenance costs) needed by the airline operators.

Figure 1.9 Boeing 787 Dreamliner (Courtesy of Agnes Blom; see Plate 9 for the colour figure)

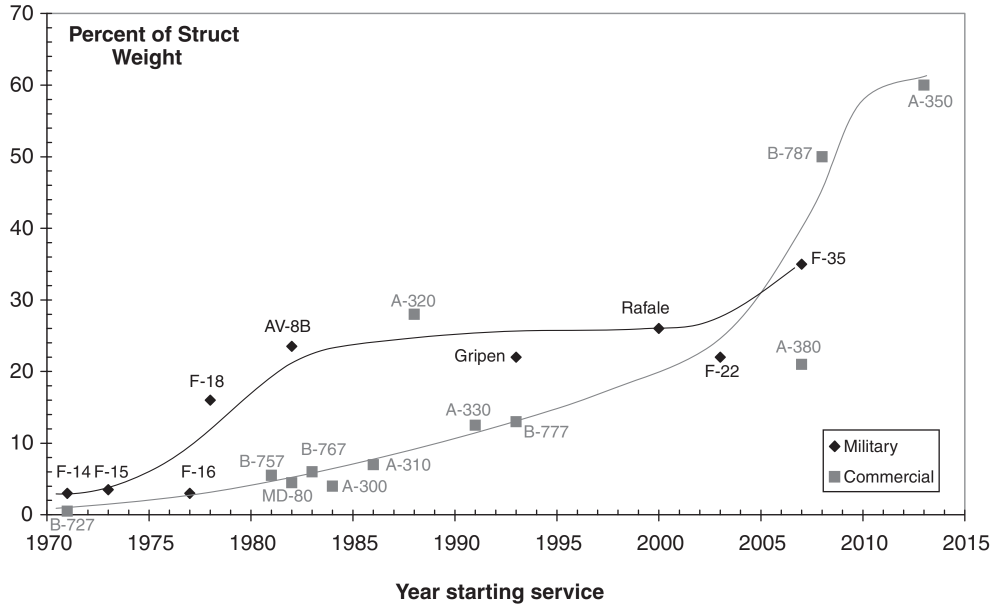

Figure 1.10 Applications of composites in military and civilian aircraft structures

The large number of orders (most successful launch in history) for the Boeing 787 led Airbus to start development of a competing design in the market segment covered by the 787 and the 777. This is the Airbus A-350, with all-composite fuselage and wings.

Another way to see the implementation of composites in aircraft structure over time is by examining the amount of composites (by weight) used in various aircraft models as a function of time. This is shown in Figure 1.10 for some civilian and military aircraft. It should be borne in mind that the numbers shown in Figure 1.10 are approximate as they had to be inferred from open literature data and interpretation of different company announcements [1–8].

Both military and civilian aircraft applications show the same basic trends. A slow start (corresponding to the period where the behaviour of composite structures is still not well understood and limited low risk applications are selected) is followed by rapid growth as experience is gained, reliable analysis and design tools are developed and verified by testing and the need for reduced weight becomes more pressing. After the rapid growth period, the applicability levels off as: (a) it becomes harder to find parts of the structure that are amenable to the use of composites; (b) the cost of further composite implementation becomes prohibitive; and (c) managerial decisions and other external factors (lack of funding, changes in research emphasis, investments already made in other technologies) favour alternatives. As might be expected, composite implementation in military aircraft leads the way. The fact that in recent years civilian applications seem to have overtaken military applications does not reflect true trends as much as lack of data on the military side (e.g. several military programs such as the B-2 have very large composite applications, but the actual numbers are hard to find).

It is still unclear how well the composite primary structures in the most recent programs such as the Boeing 787 and the Airbus A-350 will perform and whether they will meet the design targets. In addition, several areas such as the performance of composites after impact, fatigue and damage tolerance are still the subjects of ongoing research. As our understanding in these areas improves, the development cost, which currently requires a large amount of testing to answer questions where analysis is prohibitively expensive and/or not as accurate as needed to reduce the amount of testing, will drop significantly. In addition, further improvements in robotics technology and integration of parts into larger co-cured structures are expected to make the fabrication cost of composites more competitive compared with metal airplanes.

References

[1] *Jane's All the World's Aircraft 2000–2001*, P. Jackson (ed.), Jane's Information Group, 2000.
[2] *NetComposites News*, 14 December 2000.
[3] *Aerospace America*, May 2001, 45–47.
[4] *Aerospace America,* September 2005.
[5] www.compositesworld.com/articles/boeing-sets-pace-for-composite-usage-in-large-civil-aircraft.
[6] www.boeing.com/commercial/products.html.
[7] Deo, R.B., Starnes, J.H., Holzwarth, R.C. Low-Cost Composite Materials and Structures for Aircraft Applications. Presented at the RTO AVT Specialists' Meeting on Low Cost Composite Structures; May 7-11, 2001 and published in RTO-MP-069(II); Loen, Norway.
[8] Watson, J.C. and Ostrodka, D.L., AV-8B Forward Fuselage Development. Proceedings of 5th Conference on Fibrous Composites in Structural Design; 1981 January; New Orleans, LA.